Experimental Investigation of the Performance of OOK-NRZ and RZ Modulation Techniques under Controlled Turbulence Channel in FSO Systems

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***Abstract*—A number of modulation schemes have been proposed and thoroughly studied for the successful operation of the optical wireless communication (OWC). Each modulation scheme has its advantages and disadvantages for the particular channel conditions. In this paper the comparative studies of on-off keying (OOK) return-to-zero (RZ) and non-return-to-zero (NRZ) modulation techniques have been carried out experimentally under controlled turbulence channel for free space optics (FSO) communication link. Weak turbulence effect is generated within a controlled chamber of 5.5m length. The experiment is performed with a temperature gradient of 4°C at wind velocity of 1m/s. A laser source is modulated using the selective modulation schemes and optical signal is allowed to propagate through the turbulence simulated chamber. The received signal is analyzed to measure the true effect of turbulence on the optical beam carrying information. The eye-diagram and signal distributions are analyzed for comparative studies. This research work is carried out under the EUCOST ACTION IC0802 project.**

***Index Terms*— FSO, atmospheric turbulence, OOK**

I. Introduction

FSO communications or better still, laser communications is an age long technology that entails the transmission of information laden optical radiation as the carrier signal through the atmospheric channel. FSO communication offers an increased information capacity compared to the radio frequency (RF) based communication systems [1]. The very narrow optical signal provides a secure link with adequate spatial isolation from its potential interferers. The electromagnetic spectrum used in FSO is license free, its initial set-up cost is lower and the deployment time is shorter [2]. FSO can deliver the same bandwidth as optical fibre but without the extra cost of right of way and trenching, without the electromagnetic interference due to the nature of information carrier photons unlike the RF based system, it has light weight and is very compact and consumes low power [3]. The performance of terrestrial FSO is highly dependent on the atmospheric conditions. A big challenge in FSO communications is the scintillation induced by atmospheric turbulence [3, 4]. The scintillation is induced due to the random changes in the refractive index of the atmosphere results from the combination of randomly varying temperature cells, wind speed and pressure in the intended path of the optical signal propagating in the atmosphere [5,6].

To improve the BER performance of a link due to scintillations, selection of appropriate modulation schemes is an important factor which determines the overall system performance and cost [7,8]. OOK is the simple and widely adopted modulation scheme used in commercial FSO communication system because of ease in implementation, simple receiver design, bandwidth efficiency and cost effectiveness [9]. However, the performance of OOK is very susceptible to environmental conditions.

From the view point of receiver's sensitivity, RZ has been reported in [8,9] to offer better performance over NRZ in FSO links. However in turbulent-induced atmosphere, the demodulation of the received signal becomes less optimum using a fixed threshold [10,11]. Increasing the transmission power, which is limited due to eye safety regulations to combat turbulence fading results in high cost while employing optimal adaptive threshold for OOK brings complexity into the system [11].

This paper illustrates the experimental study for the performance of OOK-NRZ and OOK-RZ using different peak amplitude levels to demonstrate the effect of weak turbulence. The turbulence induced scintillations in the intensity of the optical signal decreases the performance of link significantly in a fixed threshold demodulation. The aim of the experiment was to optimize the link performance in the weak turbulence by increasing the transmission power of OOK-NRZ and OOK-RZ modulation and to compare the performance of both the modulation schemes at the same transmission power. The paper is organized as follows: the Section II outlines the experimental set-up detailing the experimental parameters, transceiver design and chamber description. The experimental results are presented in Section III, with eye-diagram, signal

ISBN: 978-1-902560-24-3 © 2010 PGNet

distribution and BER calculation. The conclusions based on the experimental results are drawn on the final section.

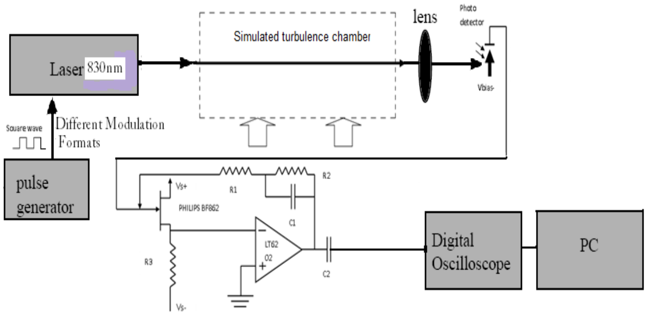
II. Experimental Description

A typical FSO link consists of a transmitter and receiver separated by the channel. The experimental set-up for the controlled study of scintillation effect on the FSO link for different modulation scheme is shown in the Fig.1. The transmitter uses a laser source with a maximum optical output power of 10 mW and a wavelength of 830 nm. The intensity of the output of a laser varied according to the modulating data format. To ensure the linearity of the system, the laser is properly biased and the peak-to-peak voltage of the input signal cannot exceed the specified values.

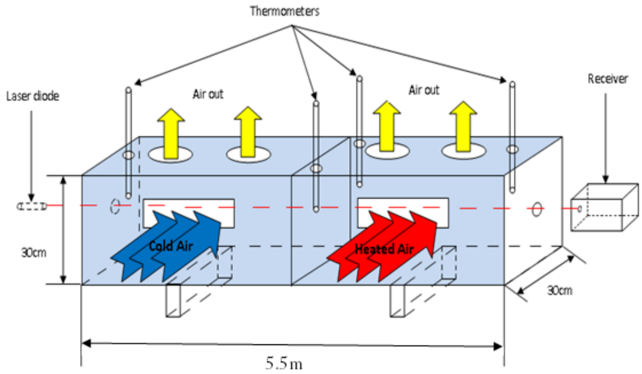
The receiver front-end consists of an optical telescope (or lens) and a photodetector. The electrical signal at the output of the photodetector is amplified using a transimpedance amplifier followed by circuitry for clock and timing recovery and regeneration of the transmitted data. The motivation of developing the chamber is to simulate the atmospheric channel affects on the optical signal traversing it at a controlled environment. Hence in the experimental set-up, data recovery circuitry is not utilized; rather the raw data at the receiver are analyzed. The complete simulation parameters used in the experiment are given in Table 1. The aim of the experiment is to demonstrate the effect of the scintillation for OOK-NRZ and OOK-RZ. The measurements are taken in similar channel conditions for the modulation schemes to achieve the optimized comparison. A periodic pseudorandom binary sequence (PRBS) of 1000 bit length is generated and converted to different signalling format as necessary to modulate the laser. The optical intensity at laser output is directly depended on the electrical input.

Table 1: Main Parameters of FSO used in the experiment

Parameters		Value
Laser diode	Peak wavelength	830nm
	Maximum optical power	10mW
	Class	Class 3b
	Beam size at aperture	5mm×2mm
	Maximum modulation frequency	150 MHz
PIN Photo-detector	Wavelength of maximum sensitivity	900nm
	Spectral range of sensitivity	750-1100nm
	Active area	1mm²
	Half angle	±75Deg
	Spectral sensitivity	0.59 A/W
	Rise and fall time of the photocurrent	5ns
	Rate	5Mbps
Chamber	Dimension	5.5×0.3×0.3m³
	Temperature range	20-80C°
	Wind speed	1m/s



(a)



(b)

Fig 1. Block diagram of the experimental set-up and (b) the turbulence simulation chamber.

The data rates, amplitude level, wind velocity and temperature levels within the chamber are given in Table 2. The emphasis of the experiment is on the simulating effect of the scintillation, and hence less focus is given on data rates, though higher data rate can be achieved with present experimental set-up. The OOK-NRZ pulse and OOK-RZ (with 50 % duty cycle γ) pulse signalling format are shown in Fig. 2. The duty cycle for RZ pulse is half of the NRZ pulse. For a constant average optical power, amplitude of OOK-RZ can be γ times that of OOK-NRZ.

Higher amplitude peak power can be beneficial in the presence of turbulence. The experiment was carried out for different peak level (see Table. 2) under the same data rate. Three temperature readings were taken at the transmitting and receiving ends and at the centre of the chamber.

Table 2: System parameters used for different modulations

Modulation Type	Modulation Amplitude (mV)	Data Rate (Mbps)	Temperature °C	Wind speed (m/s)
OOK-NRZ	50	5	24,28,27	1
	100	5		
	150	5		
OOK-RZ	100	5	24,28,27	1
	200	5		
	300	5		

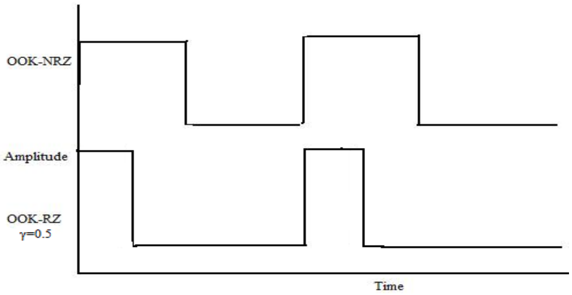


Fig 2. Signal waveforms of OOK-NRZ and OOK-RZ.

III. Experimental Results and Discussion

Experimental data for OOK-NRZ and OOK-RZ modulation schemes has been recorded for different modulation amplitudes under controlled turbulence environment and analysed using the eye-diagram and the received signal distributions. The eye diagram gives a quick examination of the quality of the optical signal before and after the turbulence.

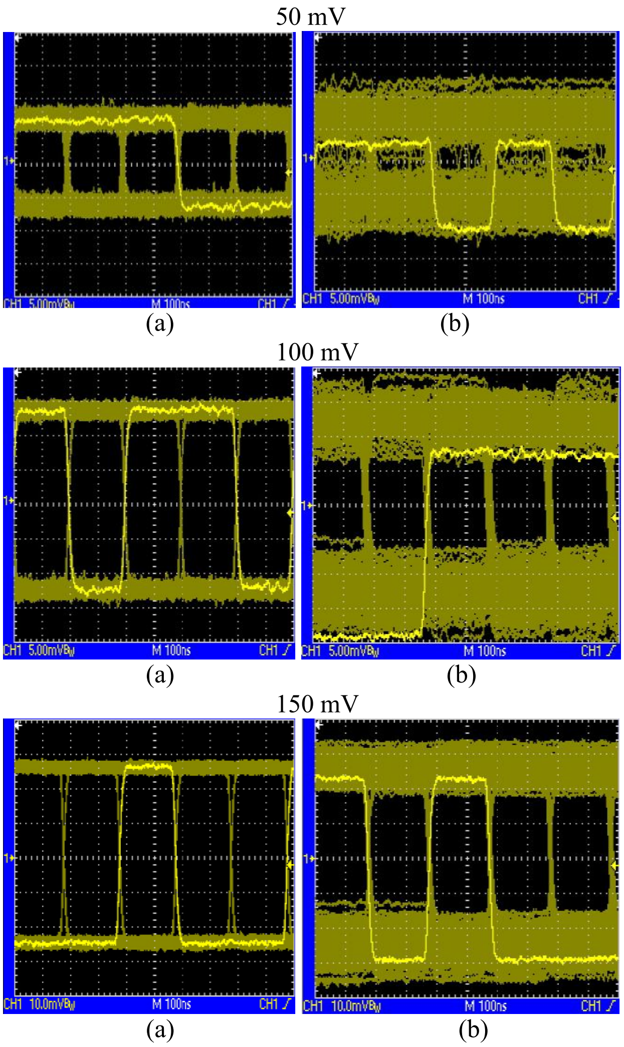


Fig 3. Eye diagrams for OOK-NRZ with modulation amplitude 50mV, 100mV and 150mV respectively (a) without turbulence and (b) with turbulence.

The received signal distributions for bit ‘1’ and bit ‘0’ has been measured for OOK-NRZ and OOK-RZ modulation schemes and plotted as an eye diagram before and after the turbulence. In Fig. 3, the eye-diagrams of the received signal with and without turbulence for OOK-NRZ at peak transmitted amplitude of 50mV, 100mV and 150mV are presented.

The eye-diagrams clearly illustrate the adverse effect of turbulence on the optical signal as the width of eye- diagram is reduced significantly for channel with turbulence compare to the channel without turbulence. Significant distortion in eye-diagram in the presence of turbulence can be observed and the error probability is expected to be very high. It is also noticeable that there is progressive reduction of eye-opening as the peak amplitude reduces form 150 mV to 50 mV meaning higher peak amplitude can be used to reduce the effect of turbulence. However, power increment to mitigate turbulence level is simple but expensive solution and also the peak power that can be transmitted is limited by eye-safety regulation. Hence a number of alternative solutions like spatial diversity, temporal diversity have been proposed details of which can be found in [3, 11] and reference therein.

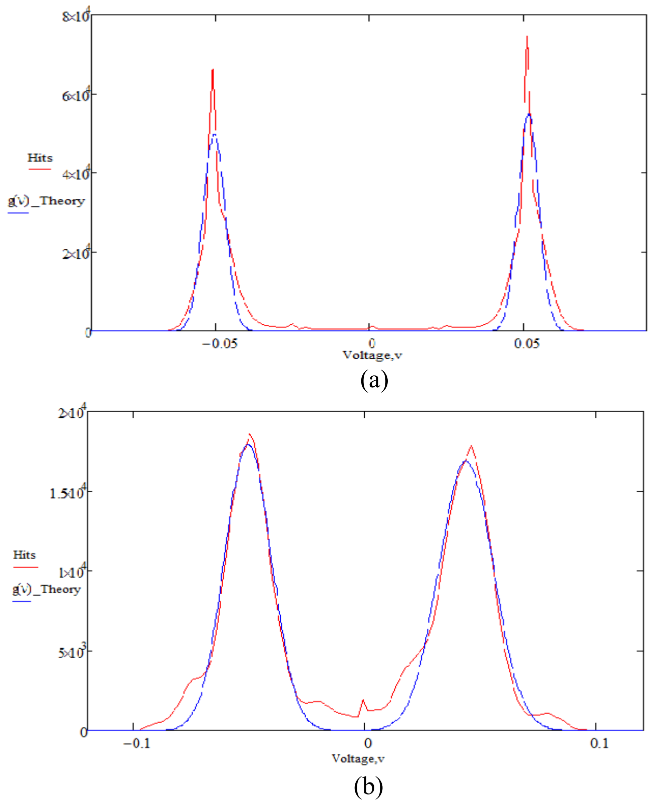
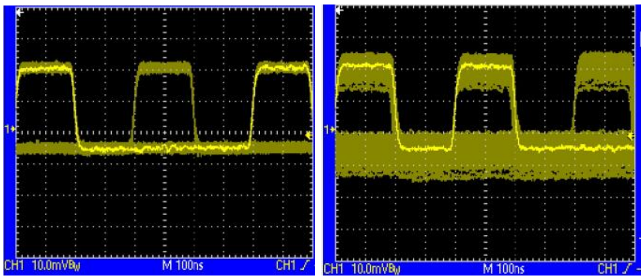


Fig. 4 The received signal distribution for OOK-NRZ (a) without scintillation (b) with scintillation (Red line: experimental data; Blue lines: Theoretical fit).

To further demonstrate the turbulence effect on the received signal, we also plotted signal histogram without turbulence and with turbulence (see appendix) for OOK-NRZ. The histogram showed that there is optimum threshold level between the received signal distribution of bit ‘1’ and ‘0’ without the induced irradiance fluctuations while with the induced irradiance fluctuations the threshold level is going to be perturbed as the variance of the distribution is going to be increase. This disturbance of the optimum threshold level due to the induced irradiance fluctuation is the worst case scenario results in the high error probability and link failure for the OOK-NRZ modulation scheme. Further the analysis for OOK-NRZ using curve fitting of two Gaussian distributions for 50mV gives average variance σ = 3.49E-3 without turbulence and σ = 0.011 with turbulence for signal amplitude respectively (see Fig. 4) increasing the error probability of the link.

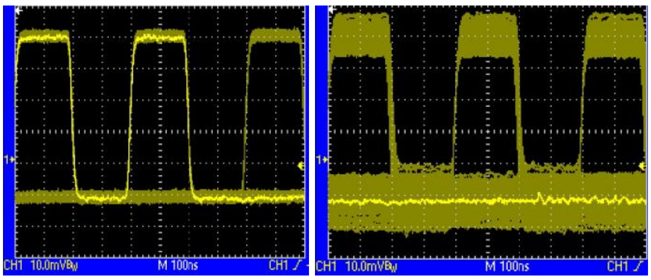
This study showed that OOK-RZ is less sensitive to the turbulence, which can be verified by comparing the eye-diagrams of OOK-RZ for the same power level compared to NRZ pulse. Unlike the case of OOK-NRZ in the presence of weak turbulence, the eye-opening is significantly wider for OOK-RZ. For like-to-like comparison the peak amplitude of OOK-RZ is made twice that of OOK-RZ. The eye-diagrams of the received signal with and without turbulence for OOK-RZ at peak transmitted amplitude of 100mV, 200mV and 300mV are presented in Fig. 5.

100mV



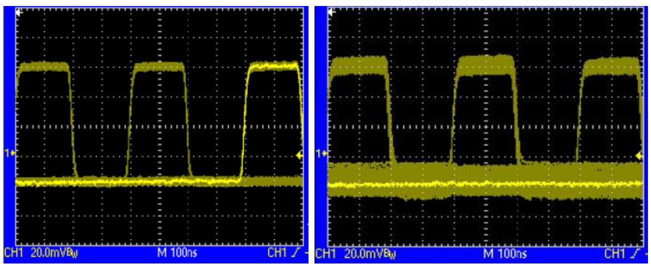
(a) (b)

200mV



(a) (b)

300mV



(a) (b)

Fig 5. Eye diagram for OOK-RZ with modulation amplitude 100mV, 200mV and 300mV respectively (a) without turbulence and (b) with turbulence.

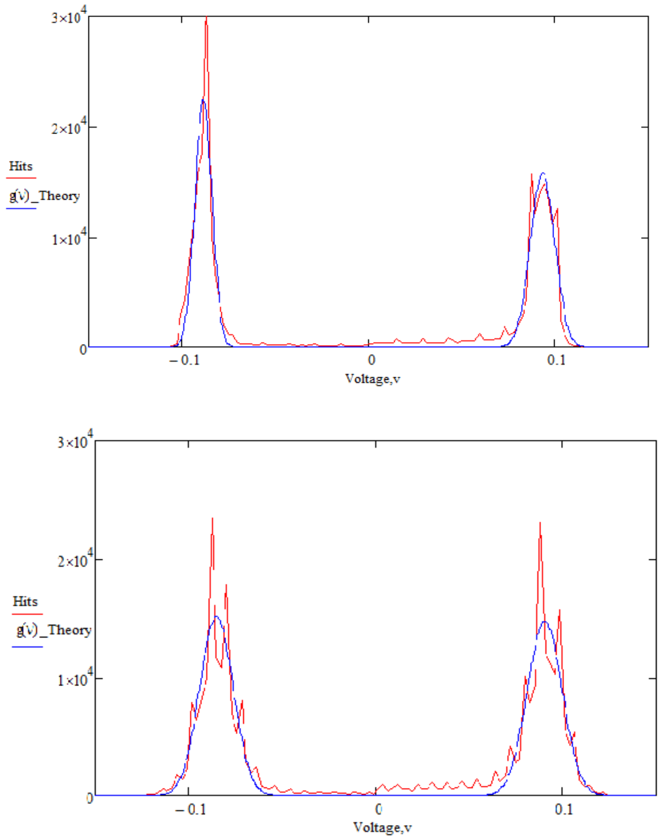


Fig 6. The received signal distribution for OOK-RZ (a) without scintillation (b) with scintillation (Red line: experimental data; Blue lines:-Theoretical fit)

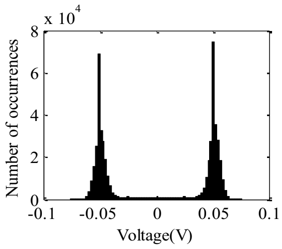
The higher peak power adopted in OOK-RZ reduces the effect of turbulence which can be noticed by wider eye opening. In fact, OOK-RZ shows significantly improved performance compared to OOK-NRZ at higher turbulence level. The advantage of the OOK-RZ schemes comes at the expense of the bandwidth efficiency. The analysis using histogram and curve fitting of two Gaussian distributions for 100mV OOK-RZ pulse returns the average variance σ = 5.58E-3 without turbulence and σ = 9.125E-3 with turbulence, respectively (see Fig. 6). Notice that the variance for OOK-RZ without turbulence is double that of OOK-NRZ as bandwidth of OOK-RZ is twice that of OOK-NRZ. However, the variance of the distribution for OOK-RZ in the presence of turbulence is significantly lower than that of OOK-NRZ leading reduced error probability.

IV. CONCLUSION

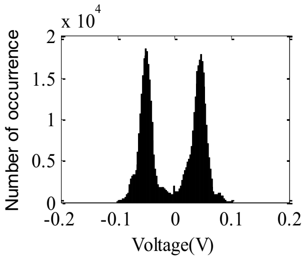
The performance of OOK-RZ and NRZ modulation schemes under controlled turbulence environment has been experimentally studied for FSO communication link. The motivation of the experiment was to understand the turbulence effect on optical signal and also to demonstrate the performance of different modulation schemes. The experimental results have shown that OOK-RZ offer significantly higher resilience to turbulence compared to OOK-NRZ. The advantage of OOK-RZ comes from the higher peak power compared to that of OOK-NRZ, leading lower error probability. Therefore the selection of suitable modulation scheme can be an effective measure to mitigate the irradiance fluctuations produced by the temperature variations and to increase the BER performance as well as the QoS of the FSO link.

APPENDIX A

50mV

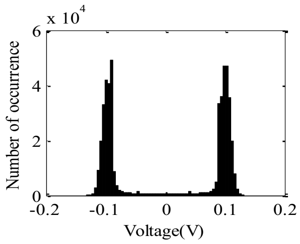


(a)



(b)

100mV



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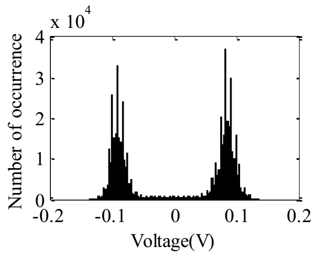

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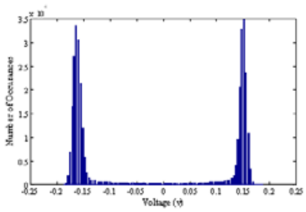
150mV



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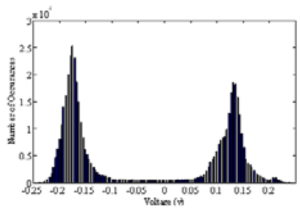
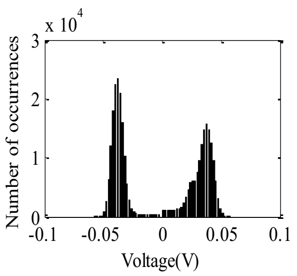


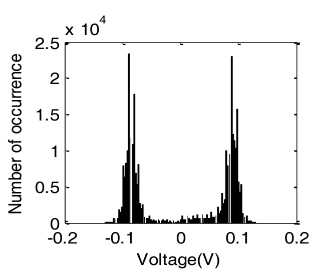
(b)

Fig 7 Received signal distributions for OOK-NRZ for peak amplitudes of 50mV, 100mV and 150mV (a) without scintillation and (b) with scintillation.

100mV

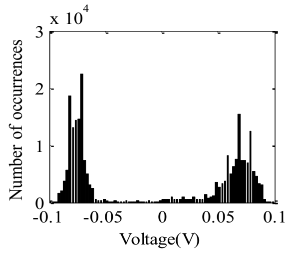


(a)

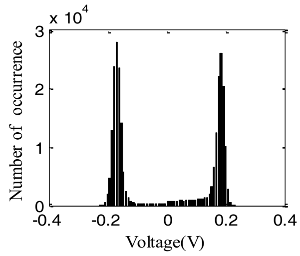


(b)

200mV

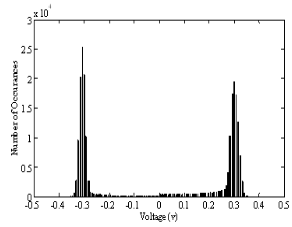


(a)

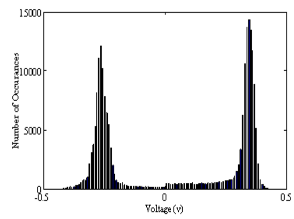


(b)

300mV



(a)



(b)

Fig 8. Received signal distributions for OOK-RZ for peak amplitudes of 100mV, 200mV and 300mV (a) without scintillation and (b) with scintillation.

V. ACKNOWLEDGMENT

The research is part of the EUCOST ACTION IC0802. One of the authors (M. Ijaz) would like to acknowledge the financial supports received from School of Computing, Engineering and Information Sciences (CEIS).

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